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## **Is the use of digital technologies for the fabrication of implant-supported reconstructions more efficient and/or more effective than conventional techniques: A systematic Review**

Mühlemann, Sven ; Kraus, Riccardo D ; Hämmerle, Christoph H F ; Thoma, Daniel S

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# Is the use of digital technologies for the fabrication of implant-supported reconstructions more efficient and/or more effective than conventional techniques: A systematic review

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## Abstract

**Objective:** To identify clinical studies evaluating efficiency and/or effectiveness of digital technologies as compared to conventional manufacturing procedures for the fabrication of implant-supported reconstructions.

**Materials and Methods:** A systematic search from 1990 through July 2017 was performed using the online databases Medline, Embase, and Cochrane-Central-Register-of-Controlled-Trials. Literature on efficiency and/or effectiveness during the impression session, the manufacturing process, and the delivery session were included.

**Results:** In total, 12 clinical studies were included. No meta-analysis was performed due to a large heterogeneity of the study protocols. Nine publications reported on posterior single implant crowns (SIC) and three on full-arch reconstructions. Mean impression time with intraoral scanners ranged between 6.7 and 19.8 min, whereas the range for conventional impressions was 8.8 and 18.4 min. In a fully digital workflow (FD-WF) for posterior SIC, mean fabrication time ranged between 46.8 and 54.5 min (prefabricated abutment) and 68.0 min (customized abutment). In a hybrid workflow (H-WF) including a digitally customized abutment and a manual veneering, mean fabrication time ranged between 132.5 and 158.1 min. For a conventional porcelain-fused-to-metal-crown, a mean time of 189.8 min was reported. The mean time for the delivery of posterior SIC ranged between 7.3 and 7.4 min (FD-WF), 10.5 and 12.5 min (H-WF), and 15.3 min (conventional workflow, C-WF). The FD-WF for posterior SIC was more effective than the H-/C-WF.

**Conclusions:** The implementation of the studied digital technologies increased time efficiency for the laboratory fabrication of implant-supported reconstructions. For posterior SIC, the model-free fabrication, the use of prefabricated abutments, and the monolithic design was most time efficient and most effective.

## 1 | INTRODUCTION

The fabrication of implant-supported reconstructions is considered a challenging process in reconstructive implant dentistry. The

traditional fabrication process for implant-supported reconstructions involves a variety of complex manual manufacturing steps, materials, equipment as well as skills and expertise of the restorative dentist and the dental technician.

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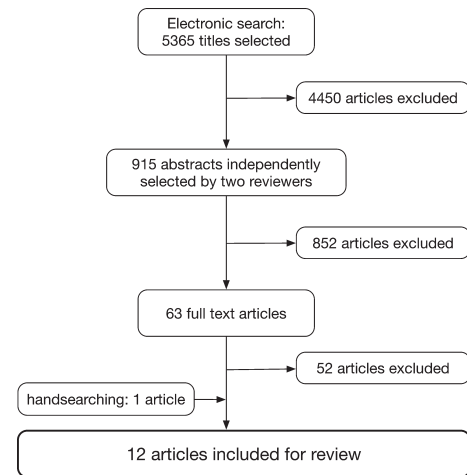
In a conventional workflow, the fabrication of an implant-supported reconstruction starts with a physical impression of the osseointegrated implant(s) with the aid of an implant transfer post. There is an abundance of literature, reporting on a possible optimization of the conventional implant impression. The focus of these studies is exclusively based on the accuracy of different impression techniques (Baig, 2014; Lee, So, Hochstedler, & Ercoli, 2008; Papaspyridakos et al., 2014). A systematic review reported that 80% of the studies compared non-splinting versus splinting, direct versus indirect techniques, and diverse impression materials (Kim, Kim, & Kim, 2015). Several clinical studies on implant impressions in the aesthetic zone reported on the proper transfer of the emergence profile from the clinical situation to the master cast by means of individualized impression posts (Hinds, 1997; Parpaiola, Sbricoli, Guazzo, Bressan, & Lops, 2013; Shah & Yilmaz, 2016; Spyropoulou, Razzoog, & Sierraalta, 2009; Tsai, 2011; Vasconcellos & Proussaefs, 2016). No information, however, is provided on the efficiency and/or effectiveness of these complex techniques.

In the dental laboratory, dental stone casts with implant analogs are poured from conventional implant impressions. In a traditional workflow, abutments and supra-structures are subsequently designed on the stone cast by means of a manual wax-up. Thereafter, the manufacturing process involves casting/pressing procedures based on the lost-wax technique. The majority of studies evaluating the lab-based fabrication process focused on qualitative outcomes. Hence, in-vitro studies predominantly reported on the fit of reconstructions (Abduo, Lyons, Bennani, Waddell, & Swain, 2011). Again, no information is given on efficiency and effectiveness of these manual laboratory steps.

Today, digital technologies offer alternative pathways in terms of impressions and manufacturing processes. The fabrication of implant-supported reconstructions by means of digital technologies may involve (a) intraoral scanning (IOS), (b) scanning of conventional impressions, conventionally fabricated models as well as wax-ups, (c) CAD of models, interim as well as final reconstructions, and (d) additive and subtractive CAM techniques (Figure 2). The time-point to enter or leave the digital workflow is based on the individual patient situation, the needs and the available digital equipment of the dentist and the dental technician.

Digital technologies offer several benefits. IOS was reported to be more time efficient compared to conventional impression techniques for single implants in vitro (Lee & Gallucci, 2013; Patzelt, Lamprinos, Stampf, & Att, 2014). In addition, the risk of dimensional changes of the impression material and any interference between different materials during the fabrication process are eliminated.

The evolution of CAD/CAM technology allowed processing of all-ceramic materials and changed treatment concepts. The chair-side concept with the delivery of an indirect ceramic reconstruction in one single visit was introduced in the late 1980s (Mormann, Brandestini, & Lutz, 1987) and significantly improved time efficiency in restorative dentistry (Mormann, 2006). In contrast, the



**FIGURE 1** Study flow chart

fabrication of an implant-supported reconstruction usually involves a lab-based fabrication process. CAD/CAM systems have the potential to increase time efficiency since time-consuming manual steps can be reduced. However, a centralized production facility is often needed for the fabrication of a digital implant analog model or a customized implant abutment allowing for an original implant abutment connection. Considering the waiting time until the delivery of the models/reconstructions, time efficiency may decrease.

CAD/CAM systems are often postulated to be more efficient and effective. Still, there is no general consent and no systematic approach has been undertaken to support or reject potential benefits of the digital workflow compared to the conventional workflow in terms of efficiency and/or effectiveness. The aim of the present systematic review was, therefore, to assess the dental literature in terms of efficiency and effectiveness of the digital and the conventional workflow at implant impression taking, during the manufacturing process of the implant reconstruction in the dental laboratory, and at the delivery of the final implant prosthetic reconstruction in the clinic.

## 2 | MATERIAL AND METHODS

### 2.1 | Protocol development and eligibility criteria

A detailed protocol was developed and followed according to the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) statement (Liberati et al., 2009; Moher, Liberati, Tetzlaff, Altman, & PRISMA Group, 2009).

### 2.2 | Focused question

Is the use of digital technologies for the fabrication of implant-supported reconstructions more efficient (with respect to time and costs) and/or more effective than the conventional fabrication method?

## 2.3 | PICO

The PICO questions were defined as follows:

**P** Population: patients receiving implant abutments and implant-supported reconstructions

**I** Intervention: the use of digital technologies in the fabrication process of implant abutments and implant-supported reconstructions

**C** Comparison: the use of conventional techniques in the fabrication process of implant abutments and implant-supported reconstructions

**Outcome:** efficiency (main outcome: time; secondary outcome: costs) and effectiveness (number of reconstructions in need for chairside adjustments/remake)

## 2.4 | Search strategy

A literature search in the online databases Medline (PubMed), Embase, and Cochrane Central Register of Controlled Trials (CENTRAL) was performed for clinical studies, including articles published from January 1, 1990 up to July 2017 in the Dental literature. The search was limited to the English and German language. An additional hand search was performed identifying relevant studies by screening the reference list of all obtained full-text articles. Search for gray literature was not attempted.

### 2.4.1 | Search protocol

The following terms were used in the search protocol:

For “population”:

- Implants  
[MeSH terms]: Dental implants OR Dental Implants, Single-Tooth OR Dental Implantation OR Dental Implantation, Endosseous OR  
[Text Words]: “implant\*”
- Abutments  
[MeSH terms]: Dental abutments OR  
[Text Words]: “abutment\*”
- Reconstructions  
[MeSH terms]: Dental Prosthesis OR Dental Prosthesis, Implant-Supported OR Crowns OR Dentures OR Dental restoration, Permanent OR Tooth, Artificial OR  
[Text Words]: “prosth\*” OR “replacement\*” OR “reconstruction\*” OR “restoration\*” OR “suprastructure\*” OR “crown\*” OR “fixed dental prosthes\*” OR “fixed partial denture\*” OR “bridge\*” OR “full-arch\*” OR “framework\*” OR “bar\*” OR “denture\*”

For “intervention”:

[MeSH terms]: Dental Technology OR Computer-Aided Design OR

[Text Words]: “impression\*” OR “intraoral scan\*” OR “intra-oral scan\*” OR “optical\*” OR “cad” OR “digital\*” OR “virtual\*” OR “cam” OR “cad/cam” OR cad-cam” OR OR “mill\*” OR “print\*” OR “cnc” OR “sla” OR “techn\*”

For “comparison”:

[Text Words]: “open tray” OR “closed tray” OR “conventional\*” OR “traditional\*” OR “cast\*” OR “veneer\*”

For “outcome”:

[Text Words]: “efficien\*” OR “time” OR “effort\*” OR “cost\*” OR “money\*” OR “finance\*” OR “economic\*” OR “bisque\*” OR “deliver\*”

### 2.4.2 | Final search strategy

(Implants AND (Abutments OR Reconstructions)) AND (Intervention OR Comparison OR Outcome)

## 2.5 | Inclusion criteria

Clinical studies, at all levels of evidence, with a minimal number of five patients, as well as investigations conducted in the dental laboratory with at least five clinical cases were included.

## 2.6 | Exclusion criteria

In-vitro and preclinical studies and reports based on questionnaires, interviews, and charts were excluded from this analysis. Investigations on provisional or interim prostheses were not considered.

## 2.7 | Selection of studies

Two reviewers (SM and RDK) independently performed the screening. Titles and abstracts were assessed for eligibility. If no abstract was available, the abstract of the full-text article was used. Disagreements were resolved by discussion between all authors. Thereafter, full-text articles of the selected abstracts were obtained. The final selection based on inclusion/exclusion criteria was made for the full-text articles. For this purpose, Materials and Methods, Results and Discussion of these studies were screened by two reviewers (SM, RDK) and double-checked. Again, any disagreement during the screening was discussed within the authors to aim for consensus. Cohen's Kappa-coefficient was calculated as a measure of agreement.

## 2.8 | Data extraction and method of analysis

Data on the following parameters were extracted and recorded in Table 1: author(s), year of publication, study design, number of patients/cases, mean age, restoration (single crown, full-arch, posterior/anterior), impression type (IOS/conventional) and impression system, laboratory fabrication system, available outcome (efficiency: time at clinical impression taking/during the laboratory fabrication process/at delivery, clinical and laboratory costs; effectiveness: need for clinical adjustments at delivery).

**TABLE 1** Description of included studies

Author/Year	Study design	Subjects n	Mean age	Restorations (n)	Impression system	CAD/CAM system	Outcome	Clinical impression taking ● = Digital ○ = Conventional	Delivery of restoration	Laboratory work
Joda and Brägger (2014)	Cohort study	6	na	Posterior SIC (6)	● iTero, Align Technology Inc		Time Costs	●	●	●
Joda and Brägger (2015a)	Cohort study, crossover	20	na	Posterior SIC (20)	● iTero, Align Technology Inc ○ polyether	Straumann Cares	Effectiveness Time Costs	● ● ●	● ○ ●	● ○ ○
Joda and Brägger (2015b)	Cohort study, crossover	20	55.4 years	Posterior SIC (40)	● iTero, Align Technology Inc ○ Impregum Penta Polyether, 3MESPE	Straumann Cares	Time	●	●	●
Joda and Brägger (2016)	Randomized controlled clinical trial	20	55.4 years	Posterior SIC (20)	● iTero, Align Technology Inc	Straumann CARES CAD/ CAM- Center Institut Straumann AG	Time Costs Effectiveness	●	● ○ ○	● ○ ○
Joda, Ferrari, and Brägger (2017)	Cohort study, crossover	44	58.1 years	Posterior SIC (50)	● iTero, Align Technology Inc	CARES X-Stream, Institut Straumann	Effectiveness	●	●	●
Joda et al. (2016)	Cohort study	20	55.4 years	Posterior SIC (40)	● iTero, Align Technology Inc ○ Polyether	CARES X-Stream, Institut Straumann	Time Effectiveness	● ○	● ○	● ○
Lee et al. (2015)	Cohort study	36	na	Posterior SIC (36)	● iTero, Align Technology Inc		Time Effectiveness	●	●	●
Schepke et al. (2015)	Cohort study, crossover	50	47.7 years	Posterior SIC (50)	● Cerec Omnicam, Sirona ○ Impregum Penta Polyether, 3MESPE		Time	●	●	○

(Continues)

TABLE 1 (Continued)

Author/Year	Study design	Subjects n	Mean age	Restorations (n)	Impression system	CAD/CAM system	Outcome	Clinical impression taking	Delivery of restoration	Laboratory work
Wismeijer et al. (2014)	Cohort study, crossover	18	na	Posterior SIC/ implant-supported FDP (na)	• iTero, Align Technology Inc • Impregum Penta Polyether, 3MESPE		Time	• ○		
Gherlone et al. (2016)	Randomized controlled clinical trial	25	57.2 years	Full-arch implant- supported FDP on 4 Implants (30)	• Trios, 3Shape • Permadyne, ESPE		Time  Effectiveness	• ○  • ○		
Palmqvist et al. (2004)	Randomized controlled clinical trial	17	na	Full arch implant- supported FDP vs. overdenture, on 3 implants (17)			Time  Costs	fixed prosthesis Overdenture	• ○	• ○
Pozzi et al. (2013)	Randomized controlled clinical trial	38	67.7/69.3 years	Full arch implant- supported FDP on 4–10 implants (38)			Time	○		

## 2.9 | Quality assessment

The methodological quality of all included studies was evaluated independently by two reviewers (SM, RDK) using Cochrane Collaboration's tool for assessing risk of bias (Higgins & Green, 2011). For non-randomized studies, the risk assessment tool was modified. Any disagreement was resolved by discussion.

## 3 | RESULTS

### 3.1 | Search

Figure 1 depicts the flow chart and selection process. The electronic search identified a total of 5,365 titles. After the evaluation of titles, 4,450 studies were discarded (inter-reader agreement  $k = 0.8$ ; CI: 0.73, 0.86). Following the screening of 915 abstracts, 63 studies were selected for full-text analysis (inter-reader agreement  $k = 0.7$ ; CI: 0.56, 0.88). Finally, 12 studies met the inclusion criteria. The reasons for exclusion of studies are depicted in Table S1: description of a digital or conventional technique without information on efficiency and/or effectiveness ( $n = 33$ ), no implant reconstruction ( $n = 5$ ), no detailed information on a specific workflow and/or a specific work step ( $n = 4$ ), in-vitro study ( $n = 5$ ), narrative article ( $n = 2$ ), interim prosthesis ( $n = 1$ ), full text not in English or German language ( $n = 1$ ), same data published in an included study ( $n = 1$ ).

### 3.2 | Description of the workflows

Figure 2 summarizes the conventional and fully digital workflow for the fabrication of implant abutments and implant-supported reconstructions. Any combination of both workflows was defined as hybrid workflow.

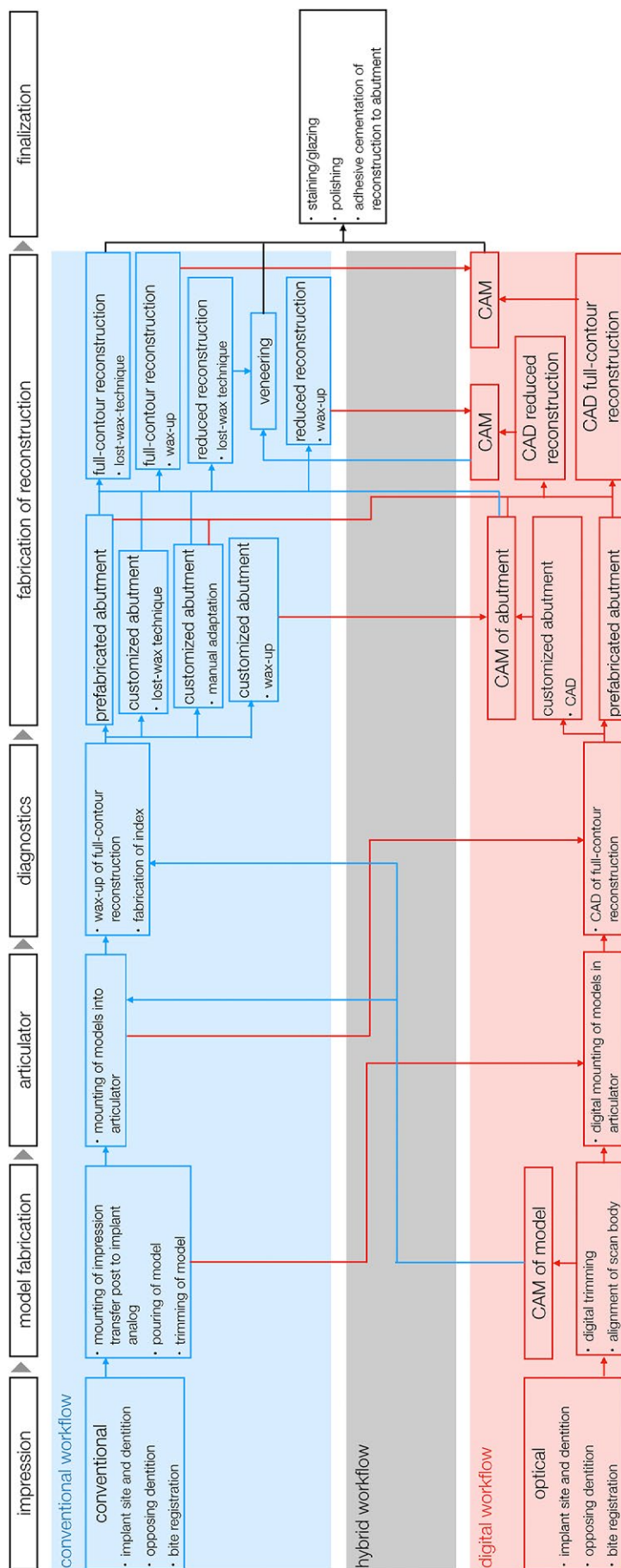
### 3.3 | Description of studies

The methodological characteristics of the selected studies ( $n = 12$ ) are shown in Table 1 and included four RCTs and eight cohort studies. Out of these studies, five had a crossover design. Nine studies investigated efficiency and/or effectiveness for the fabrication of single implant crowns (SIC) and three on full-arch reconstructions. No studies were found providing data on multi-unit fixed dental prostheses or removable partial dental prostheses. One included study reported also on the impression time for two implants (Wismeijer, Mans, van Genuchten, & Reijers, 2014). The data, however, could not be included because no information was given on whether these two implants were restored each with a SIC or with a multi-unit fixed dental prosthesis.

### 3.4 | Single implant crowns

In three studies (Joda & Brägger, 2015a, 2015b; Joda, Katsoulis, & Brägger, 2016), the same patient population was used, but outcomes and time-points varied. All three studies were therefore





**FIGURE 2** Description of conventional (blue) and fully digital workflow (red) for the fabrication of implant-supported reconstructions. Whenever the fabrication process is left to enter the digital workflow (by means of a laboratory scanner) or the conventional workflow (by transfer of a CAM-generated component), the workflow is labeled a hybrid workflow (grey) [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]



**TABLE 2** Risk of bias assessment according to the Cochrane Collaboration recommendations (Higgins & Green, 2011). For non-randomized studies, the risk assessment tool was not applicable for selection bias and was indicated by the term not applicable (na)

References	Selection bias, sequence generation	Selection bias, allocation concealment	Performance bias	Detection bias	Attrition bias	Selective reporting bias
Joda and Brägger (2014)	na	na	High	Unclear	Low	Low
Joda and Brägger (2015a)	na	na	High	Unclear	Low	High
Joda and Brägger (2015b)	na	na	High	Unclear	Low	High
Joda and Brägger (2016)	High	High	High	Unclear	Low	High
Joda, Ferrari, and Brägger (2017)	na	na	High	Unclear	Low	Low
Joda et al. (2016)	na	na	High	Unclear	Low	Low
Lee et al. (2015)	na	na	High	Low	Low	Low
Schepke et al. (2015)	na	na	High	Unclear	Low	Low
Wismeijer et al. (2014)	na	na	High	Unclear	Low	High
Gherlone et al. (2016)	Unclear	Unclear	High	Unclear	Low	Low
Palmqvist et al. (2004)	High	Unclear	High	Unclear	Low	High
Pozzi et al. (2013)	Low	Low	High	Unclear	Low	Low

included. The nine studies on SIC in the posterior areas of the jaws allowed data extraction for time efficiency at different fabrication steps: impression taking ( $n = 5$ ), laboratory fabrication process ( $n = 3$ ), and delivery of the reconstruction ( $n = 5$ ). In addition, five studies reported the number of reconstructions in need of chairside adjustments prior to delivery (effectiveness). Three studies presented a cost analysis for the fabrication of the reconstructions.

### 3.5 | Full-arch reconstructions

Two studies investigated time efficiency at impression taking, whereas one study recorded the time needed for the overall clinical and laboratory workflow. One study calculated the laboratory costs for the fabrication of full-arch fixed and removable reconstructions and one study reported on effectiveness.

### 3.6 | Risk of bias in individual studies

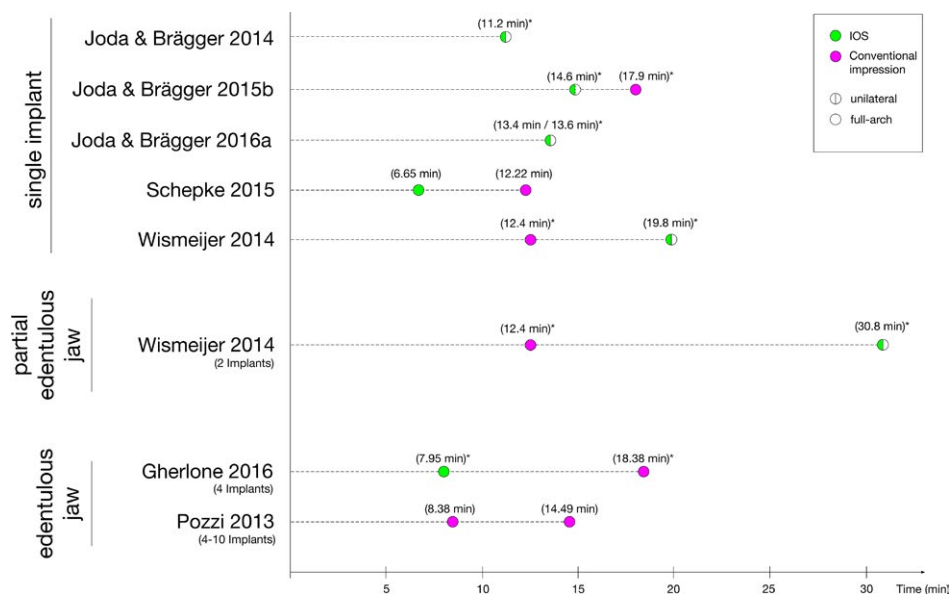
Table 2 summarizes the results of the quality assessment of the 12 included studies. Each study had at least one criterion with a high risk of bias. In particular, the performance bias was rated high in all studies and the detection bias unclear in 11 of 12 studies. Only one study reported on a separate evaluation of implant restorations by two independent examiners (Lee, Wong, Ganz, Mursic, & Suzuki, 2015). In contrast, the attrition bias was considered low in all included studies.

## 3.7 | Main outcome: Time efficiency

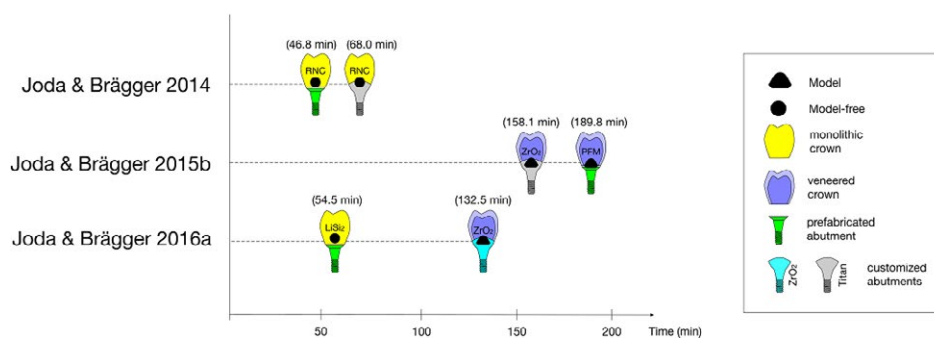
### 3.7.1 | Single implant crowns

Two IOS systems (iTero Scanner, Align Technology Inc.; Cerec Omnicam, Sirona) were applied to assess time efficiency during impression taking. In all four studies using the iTero system, unilateral impressions were taken. The preparation time was considered part of this measurement (Joda & Brägger, 2014, 2015b, 2016; Wismeijer et al., 2014). In one study using the CEREC system, full-arch impressions were obtained, but the preparation time was not taken into account (Schepke, Meijer, Kerdijk, & Cune, 2015). The mean chairside time needed to take a unilateral IOS ranged between 11.2 min (Joda & Brägger, 2014) and 19.8 min (Wismeijer et al., 2014), whereas the effective time for IOS ranged between 8.5 min (Joda & Brägger, 2016) and 10.1 min (Joda & Brägger, 2015b) (Figure 3). For a full-arch IOS 6.65 min were recorded (Schepke et al., 2015). IOS was more efficient in the maxilla (6.42 min) compared to the mandible (7.4 min). The mean time needed for a full-arch conventional impression ranged between 12.22 min without preparation time (Schepke et al., 2015) and 17.9 min with preparation time (Joda & Brägger, 2015b) (Figure 3). This included a silicone impression of the jaw with the implant, a hydrocolloid impression of the opposing arch, and a silicone bite registration.

Four studies reported on time efficiency during the manufacturing process in the dental lab (Joda & Brägger, 2014, 2015a, 2015b, 2016). Two studies (Joda & Brägger, 2015a, 2015b) reported the same



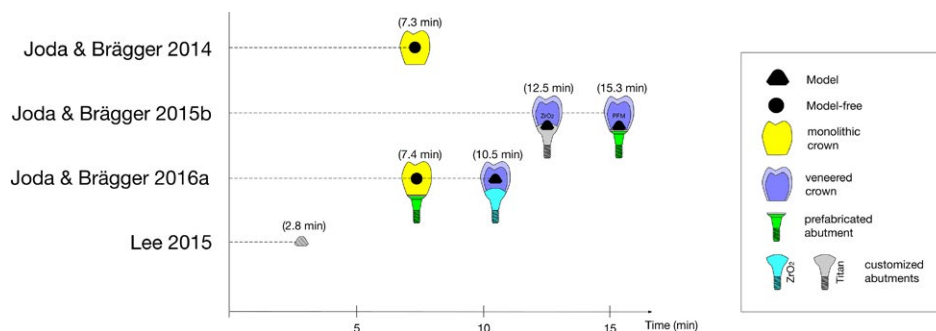
**FIGURE 3** Mean impression time (\*including preparation time). The study by Wismeijer et al. (2014) did not include the clinical time for the alginate impression to fabricate a customized impression tray before the conventional impression session [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]



**FIGURE 4** Mean laboratory working time for posterior single implant crowns (SIC); Ti = titanium, ZrO<sub>2</sub> = zirconia, PFM = porcelain-fused-to-metal, RNC = resin nano ceramic, LiSi<sub>2</sub> = lithium disilicate glass ceramic [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

outcomes and one was therefore excluded from this specific analysis (Joda & Brägger, 2015a). The same software (Straumann CARES, Institut Straumann) was used for the CAD/CAM process incorporating a centralized fabrication of the models/crowns. The overall working time for a model-free fabrication of a monolithic CAD/CAM crown bonded to a prefabricated abutment (fully digital workflow) ranged between 46.8 and 54.5 min, and amounted to 68.0 min when a customized abutment was used (Joda & Brägger, 2014, 2016) (Figure 4). Veneering of a customized zirconia abutment resulted in a more than a 100% increase in working time (74.4 min out of 132.5 min overall time) (Joda & Brägger, 2016). The comparison between a conventional fabrication method (porcelain-fused-to-metal (PFM) crown on a prefabricated titanium abutment) and a hybrid workflow (veneered zirconia crown on a CAD/CAM titanium abutment) demonstrated a mean working time of 189.8 and 158.1 min, respectively (Joda & Brägger, 2015b) (Figure 4). The fabrication of the metal framework (56.9 min) represented the most time-consuming step.

Five studies reported on time efficiency during the delivery of the final reconstruction (Joda & Brägger, 2014, 2015b, 2016; Joda et al., 2016; Lee et al., 2015). Two studies (Joda & Brägger, 2015b; Joda et al., 2016) reported on the same patient population and the one with less detailed data was excluded from this analysis after contacting the author (Joda et al., 2016). The mean time for the delivery of model-free monolithic CAD/CAM crowns ranged between 7.3 min (Joda & Brägger, 2014) and 7.4 min (Joda & Brägger, 2016) (Figure 5). In a hybrid workflow, the time for delivery ranged between 10.5 min (veneered zirconia abutment) (Joda & Brägger, 2016) and 12.5 min (veneered zirconia crown on a CAD/CAM titanium abutment) (Joda & Brägger, 2015b) and amounted to 15.3 min (PFM crown on a prefabricated titanium abutment) for the conventional workflow (Joda & Brägger, 2015b) (Figure 5). A clinical study with all-ceramic restorations (unspecified prosthetic design) on a prefabricated abutment reported a chair time ranging from 5 to 15 min (Lee et al., 2015).



**FIGURE 5** Mean time at delivery of posterior single implant crowns (SIC) [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

### 3.7.2 | Full-arch reconstructions

In a clinical study with four implants placed in edentulous jaws (17 in the maxilla/13 in the mandible), one IOS system (TRIOS, 3Shape) was applied to assess time efficiency during the impression taking (Gherlone et al., 2016). The recorded time included the placement/removal of the scan bodies, the scanning, and the bite registration (but not the impression of the opposing jaw). The mean chairside time for a full-arch IOS was 7.95 min. The time for the conventional impression involved the placement/removal of the implant impression copings, the implant impression with a polyether material, and the assembly of the impression copings and implant analogs. The recorded time amounted to 18.38 min (Figure 3). The number of retakes was lower with the conventional technique ( $n = 3$ ) as compared to the IOS ( $n = 9$ ), whereas the mean time needed for retakes was higher in the conventional group (5.82 min) as compared to the IOS (1.03 min).

In a clinical crossover study, the time for two different conventional impression techniques in edentulous patients with 4–10 implants per jaw was recorded from the placement of the last impression coping to the removal of the impression (Pozzi, Tallarico, Mangani, & Barlattani, 2013). Significantly less time was needed for plaster impressions of non-splinted impression copings (8.4 min) compared to vinyl-polysiloxane impressions with splinted impression copings (14.5 min) (Figure 3).

A randomized controlled clinical study reported the laboratory time needed for the fabrication of an implant-supported fixed prosthesis ( $n = 11$ ) and of a removable overdenture ( $n = 6$ ) in the edentulous mandible (Palmqvist, Owall, & Schou, 2004). The fabrication of the fixed reconstruction included a centralized computer-numeric controlled (CNC)—milling of the framework. The mean laboratory time was 12.5 hr (fixed prosthesis) versus 7.7 hr (removable overdenture). Both workflows represented a conventional (manual) fabrication process. The milling process was outsourced, though. The overall mean clinical time needed for the prosthodontist amounted to 3.1 hr (fixed prosthesis) and to 4.1 hr (removable overdenture).

### 3.8 | Secondary outcomes

The laboratory costs for the fabrication of reconstructions were reported in three studies (Joda & Brägger, 2014, 2015a, 2016) for

posterior SIC and in one study for full-arch prostheses (Palmqvist et al., 2004). The total laboratory costs for a model-free monolithic CAD/CAM crown on a *prefabricated* abutment ranged between 506 CHF (Joda & Brägger, 2016) and 650 CHF (Joda & Brägger, 2014), and amounted to 785 CHF (Joda & Brägger, 2014) for a CAD/CAM abutment. The costs for a directly veneered zirconia abutment were 749 CHF (Joda & Brägger, 2016) and for a veneered zirconia crown on a CAD/CAM titanium abutment 942 CHF (Joda & Brägger, 2015a). A conventionally fabricated PFM crown was charged with 1,246 CHF (Joda & Brägger, 2015a). The mean laboratory costs for a full-arch CNC-milled titanium framework veneered with acrylic resin denture teeth were 1,700 US dollars (fixed prosthesis) and 1,350 US dollars for a conventionally fabricated overdenture (removable prosthesis) (Palmqvist et al., 2004).

Outcomes on effectiveness were described in five studies evaluating posterior SIC (Joda & Brägger, 2014, 2016; Joda, Ferrari, & Brägger, 2017; Joda et al., 2016; Lee et al., 2015). In a clinical study, all PFM crowns (100%) and 60% of veneered zirconia crowns based on a hybrid workflow were in need of clinical chairside adjustments (Joda et al., 2016). 40% and 30% of veneered zirconia crowns were in need of adjustments of interproximal and occlusal surfaces, respectively (Joda & Brägger, 2016). None of 6, none of 10, and none of 50 model-free monolithic CAD/CAM crowns needed adjustments of interproximal nor occlusal contacts in three studies (Joda & Brägger, 2014, 2016; Joda, Ferrari, et al., 2017). Further data on all-ceramic crowns (unspecified fabrication process) revealed the need for clinical modifications in 36% (interproximal contact points: 17%; occlusal contact points: 19%) of the reconstructions. In addition, three out 36 crowns (8%) could not be placed without a gingivectomy (Lee et al., 2015).

One clinical study reported on the effectiveness of full-arch reconstructions (Gherlone et al., 2016). Cobalt-chromium alloy frameworks were fabricated by means of CAD/CAM either based on a conventional impression ( $n = 15$ ) or an IOS ( $n = 15$ ). The criterion for successful delivery was based on the absence of voids at the bar-implant connection assessed on periapical radiographs. In the conventional group, one framework had to be refabricated, whereas in the digital group, all frameworks were rated successful (Gherlone et al., 2016).

## 4 | DISCUSSION

The present systematic review revealed that the implementation of digital technologies resulted in a more efficient workflow for impression taking and the fabrication of reconstructions compared to a conventional workflow. IOS reduced chairside time for posterior SIC and full-arch reconstructions. The model-free fabrication, the use of prefabricated abutments, and the monolithic design of SIC resulted in more efficiency in the dental lab and in more effectiveness (no chairside adjustments needed).

Intraoral scanning demonstrated to be more time efficient as compared to the conventional impression technique. For posterior SIC, IOS allowed simplifying the scan protocol by reducing the scan area to a clinically relevant extent (unilateral instead of full-arch impression). In contrast, when taking a conventional impression, the implant transfer post generally interferes with the opposing jaw, thereby prohibiting a unilateral impression. Only one study reported that IOS is less time efficient compared to the conventional technique (Wismeijer et al., 2014). The time evaluation for the conventional impression, however, did not include the additional clinical visit, in which an alginate impression was taken to prepare a customized impression tray. Differences in time efficiency for IOS among the included studies can be explained by (a) the study protocol, (b) the brand of IOS (Patzelt et al., 2014), (c) the software version, and (d) the level of user experience and skills (Joda, Lenherr, et al., 2017). Moreover, IOS allows adding scans to an existing impression without the need for a complete retake, as necessary for a conventional impression (Gherlone et al., 2016; Pozzi et al., 2013).

The present systematic review allowed identifying the following parameters increasing time efficiency in the laboratory fabrication process: (a) model-free fabrication, (b) use of prefabricated abutments, and (c) monolithic all-ceramic reconstructions. It is important to understand that a model-free reconstruction is limited to a fully digital workflow and to date, solely based on clinical studies evaluating posterior SIC. The customization of abutments requires more time in the dental laboratory applying the digital as well as the conventional workflow. The use of ceramic materials in combination with a monolithic design of reconstructions allowed eliminating time consuming manual processes such as the lost wax-technique for casting/pressing (Joda & Brägger, 2015b) and veneering (Joda & Brägger, 2014, 2016).

The included studies did not report on the waiting time during the fabrication process. Outsourcing of a specific step in the fabrication process (centralized manufacturing) was documented to reduce the overall time efficiency (Sailer, Benic, Fehmer, Hammerle, & Muhlemann, 2017). In contrast, in a conventional workflow, the model/reconstruction is immediately available for the next laboratory work step after fabrication. No data were available on any laboratory-based waiting time due to the milling/sintering of ceramic materials or due to firing cycles for veneering/glazing in the furnace. The time efficiency during the milling process depends on the type of milling burs and the restorative material's consistency (Park, Driscoll, Romberg, Siegel, & Thompson, 2006).

The aim of both, digital technologies and conventional fabrication methods, is to fabricate a reconstruction fulfilling criteria of clinical quality. The results of three included studies (in total 66 crowns) demonstrated benefits of the fully digital workflow. No clinical adjustments were needed for model-free monolithic crowns at the day of delivery (Joda & Brägger, 2014; Joda, Ferrari, et al., 2017).

Digital technologies are associated with large financial investments. When evaluating the efficiency of digital technologies, these costs must also be considered relative to the clinical/laboratory working time. The cost efficiency during impression taking was calculated for posterior SIC: 30 CHF/min and 24 CHF/min for IOS and conventional impressions, respectively (Joda & Brägger, 2015a). The higher cost efficiency could potentially be reduced if the costs for amortization are considered. A simple calculation estimated an operating time of 36 months until the IOS device would pay for itself (Christensen, 2009). Potential updates and repairs need to be considered though.

The laboratory fabrication costs for implant-supported reconstructions were lower when using digital technologies. This calculation did not involve the costs for amortization of the CAD/CAM technology, though. Moreover, the financial benefits for the dental technician are reduced if specific steps during the fabrication process are outsourced to a centralized production. Finally, the results may only be valid for countries, in which manual laboratory work is more expensive than the industrialized process.

The scientific evidence obtained through the present systematic review is limited to few clinical studies, posterior SIC and full-arch reconstructions. Different study protocols were applied during impression taking. In addition, the laboratory fabrication process of implant abutments and implant-supported reconstructions allows applying digital technologies at any time-point resulting in a hybrid workflow. Thus, heterogeneity among the included studies was distinct and data were difficult to compare.

Further clinical studies on time efficiency should include an exact description of the applied digital technologies as well as the work step that they are involved (Figure 2). The impression time should include all clinically relevant information to allow fabricating a reconstruction by a dental technician: (a) jaw with implant, (b) opposing jaw, (c) bite registration. In addition, time analysis should separately report on preparation time (including placement/removal of scan body/impression transfer post or time for powdering) and scan time. A clinical study on tooth-supported crowns demonstrated that time efficiency changes among IOS when including/excluding preparation time (Benic, Muhlemann, Fehmer, Hammerle, & Sailer, 2016). In the dental laboratory, a clear distinction should be made between lab-based and centralized CAD/CAM processes. In addition, waiting times should be included in the time analysis.

Although randomized controlled clinical trials (RCT) are considered to provide the highest scientific evidence, a crossover design might be considered more appropriate to evaluate efficiency and/or effectiveness during the fabrication process. To provide high-quality clinical crossover studies, (a) an independent investigator should

perform the time recordings and (b) blinding should be applied to evaluate effectiveness at the delivery of the final reconstruction, wherever possible. Still, for follow-up studies evaluating survival and success rates of reconstructions fabricated with the aid of digital technology, an RCT design is most appropriate.

## 5 | CONCLUSION

The scientific evidence obtained through the present systematic review is limited to few digital systems. The implementation of digital technologies for the laboratory fabrication of posterior SIC showed to increase time efficiency. The model-free fabrication, the use of prefabricated abutments, and the monolithic design of posterior SIC resulted in more efficiency in the dental lab and in more effectiveness (no chairside adjustments needed).

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## SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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